BOX CAR DESIGN PROJECT

Rail transportation has played an important part in the development of our country and in the standard of living which we enjoy today. It has influenced the growth of cities and the location of industrial centers, the development of communication and the price of food. Because of the immensity to which our rail system has grown, it has not been subject to the same technological development as the other industries which it serves. In particular, the movement of freight, whether through lack of foresight or resistance to change, has remained essentially the same since the first transcontinental right of way was joined with the golden spike. The bulk of freight traffic is moved in outmoded box cars, the standard carry-all of railroad transportation. As we look around us, it is hard to understand how box cars and cargo-carrying airplanes can be products of present-day engineering. The ox-cart and diesel truck seem no further apart.

Prepared under the direction of John E. Arnold at the Massachusetts Institute of Technology.

It is seen that highway traffic has been increasing and railway traffic decreasing in their relative share of transportation as measured in ton-miles. The total 1951 ton-mileage was 1,119 billion. The motor carriers produced about 133 billion intercity ton-miles. Somewhat over one-half of the highway mileage is produced by for-hire carriers and somewhat less than one-half by private carriers, the percentages being 56.6 and 43.4 respectively. In that year the for-hire mileage was 93.3 per cent by common carriers and 6.7 per cent by contract carriers. Undoubtedly, the ton-mile potential is very high. It should be borne in mind that motor carriers "pick and choose" the high-grade commodities, which is reflected in their average earnings per ton-mile. In 1951, for instance, the motor carriers averaged 5.16 center per ton-mile, whereas the railways grossed, due to the preponderance of low-grade tonnage, only 1.34 cents. This, of course, means that the motor carriers' share of gross revenue was far greater than their share of ton-mileage.

Relative Shares of Intercity Freight Traffic, Public and Private,
by Kinds of Transportation
(Per Cent of Total Ton-Miles)

Year	Railways*	Highways	Inland Waterways**	Pipelines	Airways
1939	64.26	8.33	16.86	10.55	***
1940	63.36	8.36	18.38	9.90	***
1941	64.72	8.50	17.59	9.19	***
1942	71.08	5.36	15.29	8.27	***
1943	72.79	4.60	12.91	9.69	0.01
1944	70.19	4.45	12.87	12.48	0.01
1945	68.90	5.33	13.14	12.62	0.01
1946	68.64	7.33	13.11	10.91	0.01
1947	67.55	7.92	13.82	10.69	0.02
1948	64.39	8.72	14.97	11.90	0.02
1949	61.41	10.76	15.20	12.60	0.02
1950	58.77	12.40	16.08	12.72	0.03
1951	58.57	11.90	15.91	13.59	0.03

* Steam and electric, including mail and express
** Including Great Lakes
*** Less than 0.005 per cent

Unfortunately, we are saddled with the great bulk of existing rail equipment as we approach our problem. Roadbeds are not converted to monorail overnight, and loading platforms can not all be changed to conveyor systems. It is in freight traffic that railways stand in greatest need for improvement. There is perhaps no more uneconomical appliance than a railway freight car. It has been estimated that 12 per cent of a freight car's life is spent in normal road movement, 66 per cent of which time it was running loaded in 1950 and 34 per cent it was empty. The balance of its life is spent in yard movements or standing still on sidings, in terminals, shops, at loading platforms, etc. Improvements can be made which

are compatible with existing equipment. New loading and storing devices, new suspension systems, lighter and stronger underframes, more rugged construction techniques, greater flexibility, new freight handling methods, and lowering of construction cost may be coupled with totally new operational techniques which would result in faster service with lowered freight rates. These changes must come, with many more, because speed and cost of rail transportation influence the nation's economy more than any other single factor. Although we are confining ourselves to the study of box car design, we must create with the entire structure of freight movement in view. Real contributions may stem from the approach of the creative engineer.

Background Information

Box cars are primarily employed to transport valuable commodities requiring protection from the weather or against breakage. Besides the plain type of box car intended for ordinary freight traffic, there are box cars made to accomodate the products peculiar to cartain industries such as the automobile, furniture and lumber, and the raising of agricultural products. R. R. freight tonnage in 1949 was distributed as follows:

Products of agriculture - 11.1%
Animals and products - 1.4%
Products of mines - 49.2%
Products of forests - 6.3%
Manufactures and misc. - 30.5%
L.C.L. freight - 1.1%
C.L. (forwarder traffic) - 0.4%

Based on types of cars available about 45% of this tonnage was carried in "box" cars.

Express box cars equipped for passenger train operation are constructed essentially the same as those in freight service, but are fitted with air, signal, and steam-heat pipes, and have passenger car-type air brakes and high speed trucks.

Association of American Railroads Official Designations of Box Cars

Class "C" - Box Car Type:

"XM" - Box. A house car for general service and especially for lading requiring protection from the weather and equipped with side or side and end doors.

"XAR" - Automobile Device. A house car similar in design to the "XM" Box, except unlined with side or side and end doors and equipped with loading racks and/or floor tubes with tie-down chains for loading setup automobiles and trucks and suitable for general service loading of other miscellaneous commodities.

"XMR" - Automobile Device. A house car similar in design to the "XM", fully lined, with side or side and end doors, equipped with loading racks and/or floor tubes with tie-down chains for loading setup automibiles and trucks and suitable for general service loading of other miscellaneous commodities.

"XAP" - Automobile Parts. A house car similar in design to "XM", but specially equipped with permanent interior fixtures for stowing automobile parts, not suitable for general service loading of other miscellaneous commodities.

"XML" - Loader Equipped. A house car similar in design to "XM", either fully or partially lined with steel perforated sidewalls or equipped with protruding interior side rails, stanchions and crossbar members for stowing automobile parts and adaptable for certain other commodity loading.

"XME" - Merchandise Loading. A house car similar in design to the "XM" with wooden lining and fitted with interior stowing fixtures, but which notwithstanding such stowing fixtures can be used for general service loading.

"XMP" - A house car similar in design to "XM", but specially equipped for specific commodity loading other than automobiles and their parts, and not suitable for miscellaneous commodity loading.

"XI" - An insulated box car, similar in design to "XM", but either wholly or partially insulated, not equipped either with ventilating devices or for refrigeration.

"XT" - A house car, with or without doors, with or without insulation, either metal lined or enclosing one or more tanks.

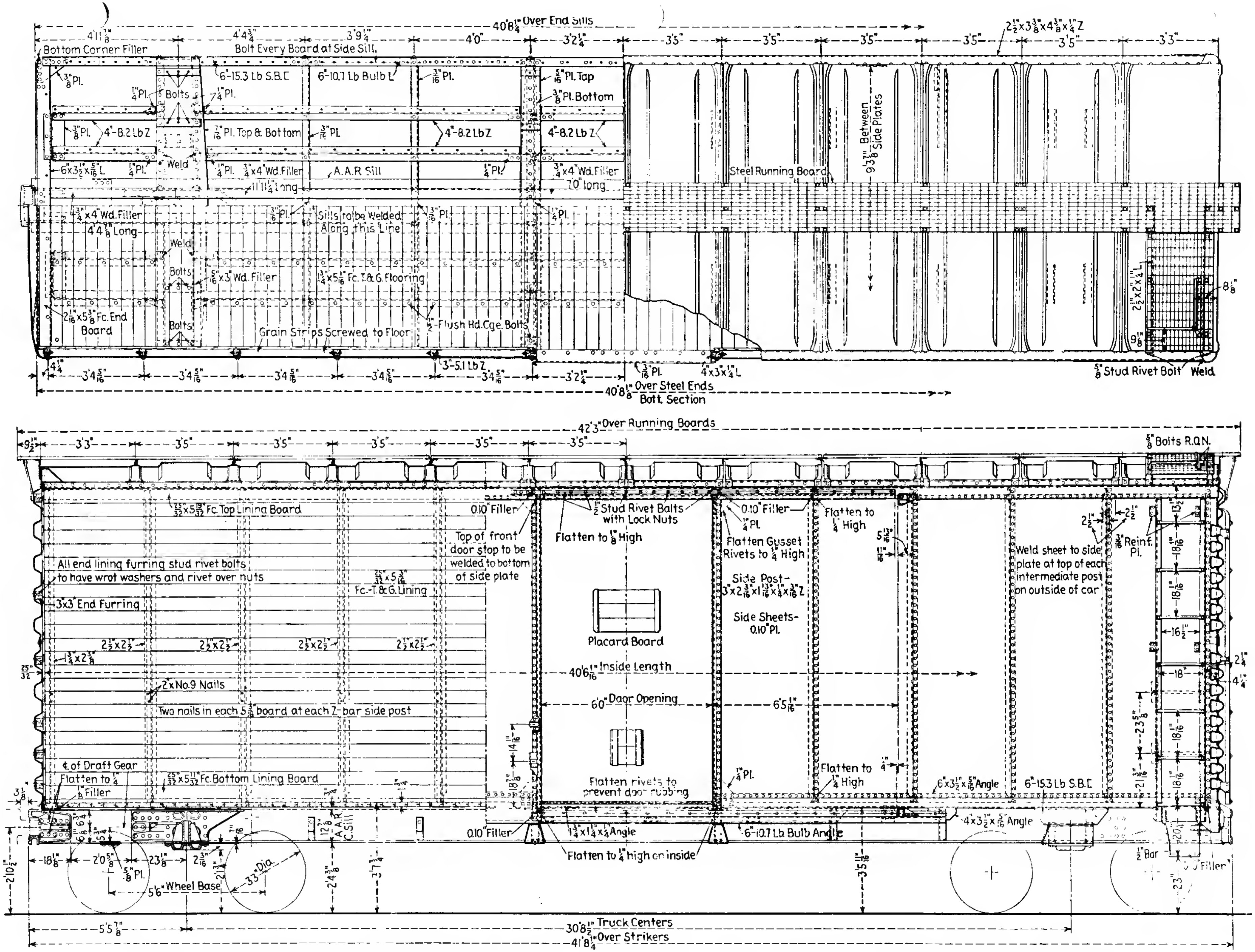
Any of the above cars may be equipped with heaters for the protection of the commodities and are designated by the affixing of the letter "H" to a box car type. There are also express box car classifications, and a "V" series car, with provision for ventilation but with no refrigeration.

There are 24 designations for box cars, but since a large majority of the standard A.A.R. box cars are patterned after model XM, its size and specifications are representative of the typical modern box car, with a few exceptions, which will be discussed later.

The standards set for box cars cover three lengths; nominally forty, fifty and sixty feet respectively. By far the most common car is the forty foot model. Its actual dimensions are as follows:

Inside Overall Length: 40 ft. 6 in.
Inside Overall Width: 9 ft. 2 in.
Inside Height at Eaves: 10 ft. 6 in.
Outside Length (over strikers): 41 ft. 10 in.
Outside Width (over side sills): 9 ft. 9 in.
Outside Height (from floor): 11 ft. 5 in.

Other dimensions may be secured from the available A.A.R. drawings of this car in the "Car Builders Cyclopedia". The fifty and sixty foot models share most of the above dimensions, except that their inside length is respectively fifty feet, six inches, and sixty feet, six inches, and the outside length appropriately greater.



Erie 50-ton steel-sheathed wood-lined box car, series 81000-81799. Inside dimensions: 40 ft. 6 in. long, 9 ft. 2 in. wide, 10 ft. 4 in. high at eaves.

Some slight deviation from these measurements, one inch or fractions thereof, exist in privately constructed and Canadian-built cars.

Box cars are also nominalized weightwise, that is, by their loading capacity. Today, the most common size is the "40 ton" car. This type, closely followed in numbers by the "50 ton", has a nominal load of 80,000 lbs. Its load limit is actually about 98 or 99 thousands pounds. The light (unloaded) weight of a forty ton car is about twenty tons, so that the combined maximum weight of the loaded car on the rails is usually about 135,000 lbs. There are small variations in these figures, but like the deviations from standard dimensions, are usually quite small. The fifty ton car, (which is, also, a forty footer built more heavily) has a nominal load of 100,000 lbs, a load limit of about 121,000 lbs, and an empty weight of about 48,000 lbs, totaling almost 170,000 lbs fully loaded.

There are some 55 ton box cars in use, with a corresponding upping of weight and load limit. All of the above may have side door openings of six, seven, or eight feet zero inches. The automobile cars and automobile box cars, "XAR" and "XMR", have double doors, doubling any of the above door openings. The most frequent size for the two classifications is the 50 foot six inch, 50 ton car. The American Association of Railroads report for May, 1953, shows that of the approximately 2,100,000 cars in use, 731,000 were box cars, 131,000 were refrigerator cars, 50,000 were stock and poultry cars, 70,000 flat cars, 910,000 gondola and hopper cars, 130,000 tank cars; and the balance were cabooses and other cars.

The load carrying capacity of box cars is determined by the axle size of their trucks. Axles with journal bearings 5-1/2" in diameter and 10" long are good for 169,000 lbs. on the railhead, and axles with journals 6" x 11" will carry 210,000 lbs. That is, the sum of the lightweight of the car, and its lading, always assuming four axles per car, cannot exceed the above given weights on the rail. Thus, a box car with 5-1/2" in diameter x 10" axles, weighing 50,000 lbs. light, cannot carry more than 169,000 - 50,000, or 119,000 lbs of useful load, and this is the number stenciled on the car side after "Load Limit". There are certain requirements in the A.A.R. Loading rules that must be met in distributing the weight of the commodities. In general, they seek to avoid heavy point loads and try to maintain the heaviest packing over the kingpins, and not in the center of the car. A useful ratio as far as the design of box cars of a lighter nature than standard is concerned is the tare ratio. This fraction is the total useful lading weight divided by the weight of the car, or tare weight. It gives a constant for any car in terms of the pounds of useful load, or load carrying capacity, per pound of dead construction weight.

Design Information

Some consideration of the stresses involved in freight car design is necessary in order to have some grasp of the sizes of the forces involved, and some figures from the Engineers' office of the Pennsylvania Railroad (the country's largest owner and operator of freight traffic) are herewith given.

Standard box cars are designed to take a compressive force of 250,000 lbs. exerted at the centerline of the coupler, and, hence, through the centerline of the heavy underbody main beam. Most cars are fabricated of plain carbon steel, either cast, or stamped, and the combined stresses due to vertical load and compression should not exceed 16,000 psi for this material. Most abuse of freight cars comes in coupling, where high speeds exceed the recommended rates, and prohibitive forces are exerted on the car. Generally speaking, a standard box car designed for 250,000 lbs buff can be coupled repeatedly at 4 m.p.h. without sustaining any damage.

Transverse forces do not enter into stress calculations other than in the computation of resistance to the bulging caused by bulk and grain loads in box cars. Experience has indicated the need for an extra strong side member at the lower doorframe, where loading takes place, due to careless managing of loaders, small cranes, and blows with grab buckets and similar devices.

The side plates and smooth fabricated parts of box cars are computed on the basis of a yield for the carbon steel of which they are made of 32,000 lbs. By designing for a maximum stress of 16,000 psi, a safety factor of 2 is secured. However, the excessive use of light plates, thin sheet, and light (section) structural members is always avoided because of loss of section from corrosion, and as a result of this practice, many parts of a car have a safety factor much higher than 2.

The underbody framing of a box car is subjected to heavy tensile loads during sudden starts or pull-outs. The coupler is designed to take up most of this shock, and it usually stands up well. Occasionally, the coupler knuckle may fail, but seldom the shank itself. The knuckle has a yield of 225,000 lbs., and an ultimate strength of 550,000 lbs. The coupler yoke has a yield of 399,000 lbs., and an ultimate strength of 735,000 lbs. Freight draft gears go solid at about 270,000 lbs., but all approved draft gears must have a minimum capacity (ability to absorb kinetic energy) of 18,000 ft-lbs, and therefore, the reaction taken by the car through the draft stops is usually not damaging. To summarize, on an exceedingly heavy pull out, we can expect failures of components in about the following order: coupler knuckle; draft gear; center sill.

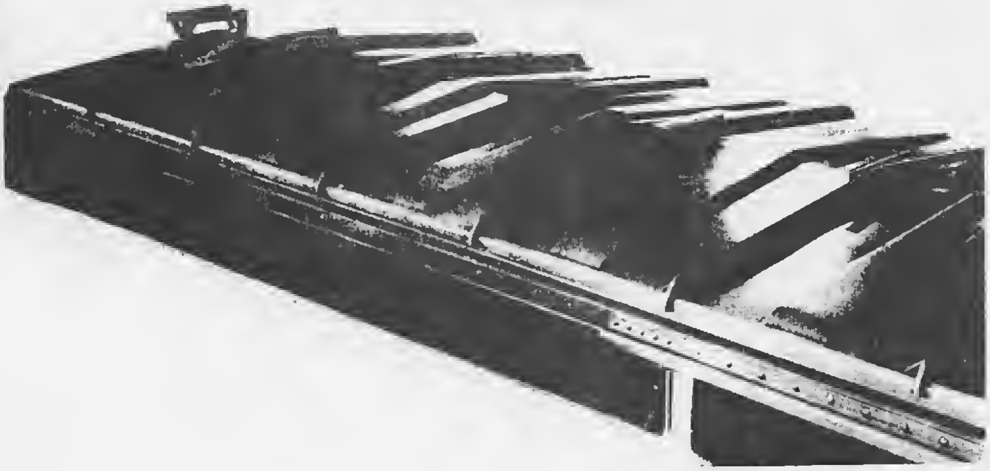
Such heavy pull-outs are examples of maximum accelerations and decelerations to which cars are subjected. Other frequent causes of extreme accelerations are humping in yards at excessively high speeds (over 5 mph) and slack action on the line due to uneven brake action. A longitudinal acceleration of 1.25 G is severe for a box car, and likely to cause damage to lading. Unfortunately, such values are not uncommon, and they are

encountered particularly in switching operations. Right now, many of the railroads are engaged in an all out safety campaign, one of whose main objectives is the lowering of humping and coupling speeds to prevent excessive freight damage, which has been the cause of considerable loss of revenue in the past.

A reasonable method of arriving at the price of a standard A.A.R. box or auto-merchandise car is to assume a figure of about 11.5 cents per pound, delivered. Thus, a forty ton, forty foot "XM" car will cost 11.5 x 40,000/100, or $4600, and a large automobile-box car of 55,000 lbs. light weight will cost 11.5 x 55,000/100 or almost $6,400. Actually, this rule of thumb has changed somewhat, even in the last year, and it is pretty reasonable to assume the former cost now to be between five and six thousand dollars, and the latter proportionately higher also. A good average figure for 50 ft. cars is $6,500, which comes to about 13 cents per pound. Special service cars, equipped with such extras as ventilators, heaters, insulation, etc., push this price up to about 14.5 cents per pound, and refrigeration equipped cars, either mechanical or with modern ice-handling equipment go up to about 15 cents per pound.

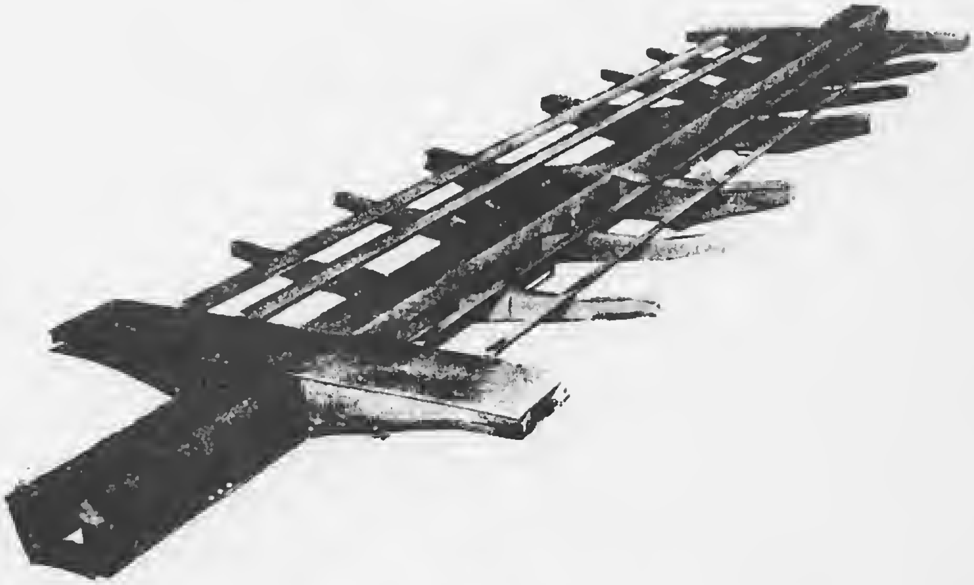
All of the above figures refer to the standard approved cars now in wide-spread use all over the country and in Canada. There have been some improvements made, and many attempts to improve these carriers recently, and perhaps the most frequently repeated experiment has been the building of aluminum cars. Figures for an average aluminum-sided, steel-framed box car are: 40 t. 6 in. type, nominal class loading, 50 ton, light weight 43,500 lbs. This car is lined with a high-strength, aircraft type plywood, sheathed with aluminum and has a standard steel underframe riding on high speed trucks. While apparently it presents a great weight saving (4,500 lbs.) over comparable steel cars, its cost is very high comparatively, and several companies have already built 40 ft. 50 ton, all-steel all-welded cars that weigh in at 44,000 lbs. light, thus cancelling any of the aluminum car's advantages, at least for the present.

Another more successful venture has been the experimentation in fabrications and reduction of parts made by the Pullman-Standard Company. By converting to an all-welded car, and using prefabricated, jig-built sections, they have reduced the number of parts in a box car by hundreds, or if rivets can be considered parts, certainly thousands. The components of a P.S. box car when ready to assemble, look exactly, with no apparent differences, like the contents of an Athearn model box car kit. The stamped ends are the only riveted covering, being joined across their center horizontally by a single riveted seam into the large corrugated end plate. Everything else, roof included, even the underframe, is welded with the help of large fixtures, and the weight figures for the car, designated the PS-1, are very favorable, reading as follows: total weight on railhead: 169,000 lbs., light weight; 44,100 lbs., load limit; 124,900 lbs. nominal class; 50 ton (40 ft.).



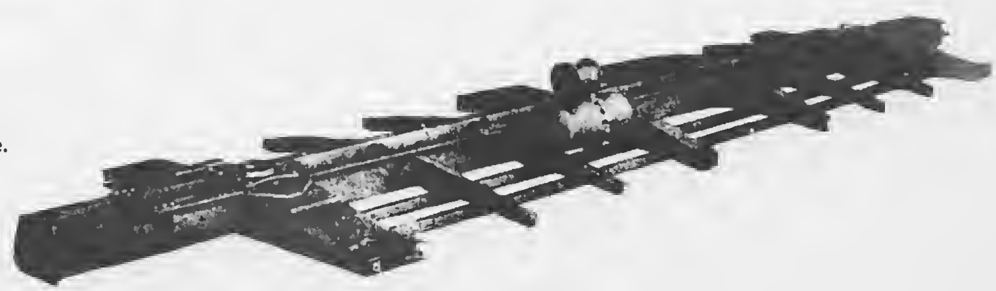
Arc-welded roof — Running boards removed.

Top view of underframe. Welded draftsill construction with built-up welded bolster and continuous stringers.



Section or cut away view of draft sill and bolster showing built-up construction.

Bottom view of underframe.



Details of PS-1 standardized box car.

Pullman-Standard Car Manufacturing Co.

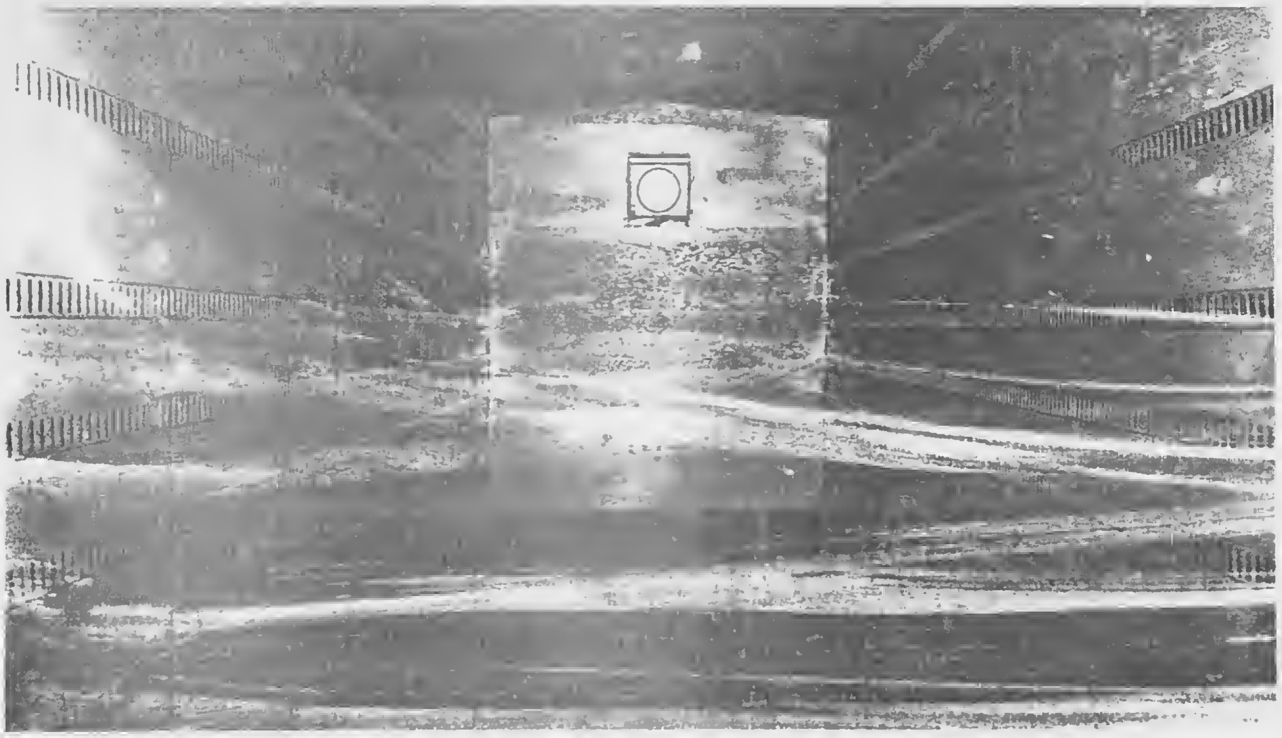
Very little of the welding on these cars is done by hand; most is automatic arc welding done on gantries or specially built machines. A.C.F. has taken up the same techniques, concentrating on refrigerator types, and their first venture was the spectacular "100 mile-an-hour-reefer", an all welded, lightweight steel refrigerator car equipped for passenger runs. This car was very successful, as was the PS-1, and both are being built steadily.

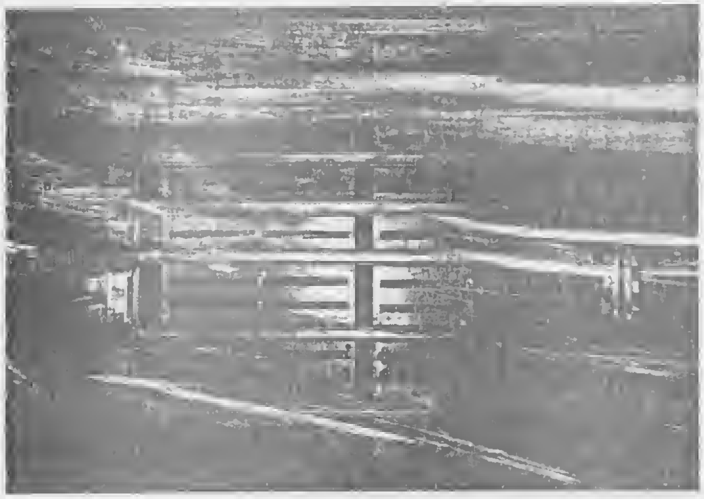
Both of these steel cars are improvements on the old type of riveted cars. (It is somewhat astonishing to learn that there are still more wood, outside braced box cars on American railroads than any other type.) Alcoa is now experimenting, not so much with entire cars, as with aluminum corrosion-proof components of new design for box cars. Examples of this are their open type running roofwalks that pass snow and are easier to grip than old solid steel walks, and a real improvement, the lightweight aluminum door.

While there has been a great deal of experimenting with external box car design (although with no really radical design changes), internal improvements are far behind. The wood lining, which is needed in many box cars, and in all reefers, is always laid by hand, and the A.A.R. still specifies a separate-board, tongue and groove type flooring in their standard car. There has been some little experimentation with plywood interiors, and in one case, a plywood exterior (the Unicel refrigerator). However, a really good, cheap and tough exterior liner that can take a beating, have quickly attachable fittings and be easily installed and replaced is still lacking. Cars that do not have wood interiors may be either unlined or have a special steel lining, that permits fixtures to be used for freight securement.

Since damaged-in-transit claims are quite costly (135 million dollars paid in claims in 1952), a number of devices have been introduced to minimize damage.

These freight securement fixtures are of several types. Perhaps the most common is the slotted car lining type, on which there are many variations. In this type of retainer, the lining of the car is built so that narrow horizontal slots running the length of the car are exposed on the sides. These slots have vertical pins spaced evenly down the car, and when loads are placed in the car, standard bars can be placed across the car, braced against the lading to prevent shifting, and locked in place in the slots. One system (Barber) uses steel tapes of the standard packing variety to hold the load in place. These tapes are disposable. Other types use standard pipes with special end fittings, or wooder bars with steel tips, for the crosswise members. The Milwaukee Road has a ratchet device in its bars that allows them to be slid down the slots across the closely-spaced holes in the groove plates and locked at any time. These latter systems with removable bars usually have some provision for their storage in the car. The "Pennsy" has a system of its own, in which the car is equipped with sectionalized gates hinged to the sides down the car.

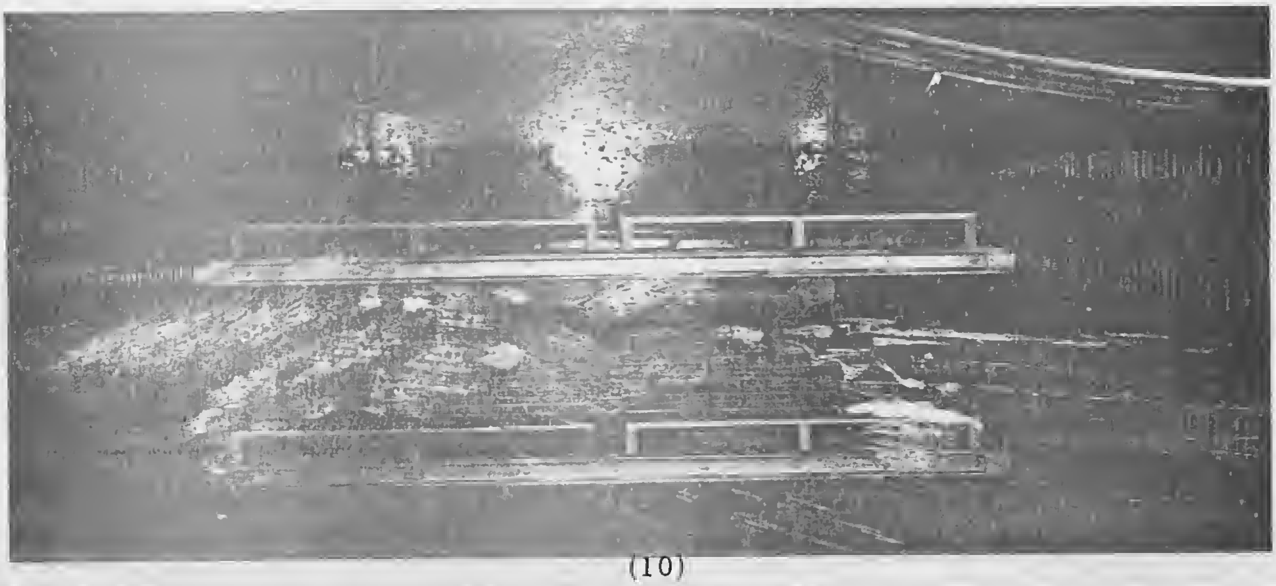




Above—General interior view of Chicago, Milwaukee, St. Paul & Pacific box car equipped for load bracing and multiple-deck loading.

Left—Racks placed for bulkheading.

Below—Horizontal racks in place for multiple-deck loads.

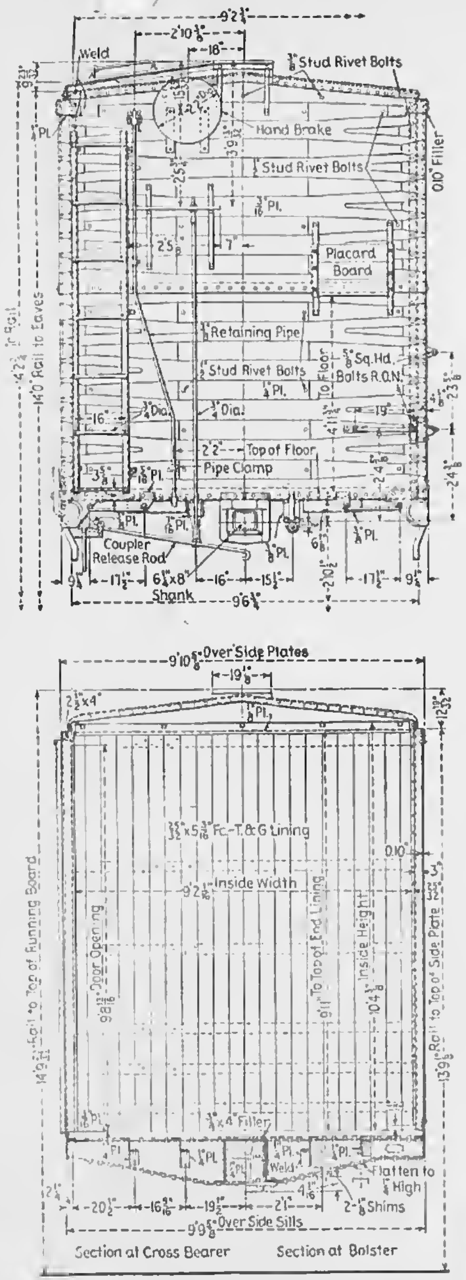


These gates may be swung open and locked together at their centerline junction. Usually three gates at each position add to reach the full car height, or any third thereof, when opened, and all three fold back against the car side when not in use. Many automobile cars have a perforated or tubular floor, which allows the attachment of chains which hold the loads in position. These are "XAR" and "XMR" types and can be used for other machinery and heavy lading besides automotive equipment. The "XAP" types, however, are permanent auto fixture cars and cannot be adapted for anything else. An example is the Ford "EB" car, a standard steel unlined box car fitted with a serpentine track in which slide heavy pulleys with chains attached. These unit pulleys support engine blocks, which hang by a single threaded rod, and are stabilized by a single chain fastened to the steel flooring.

The Evan "DF" (Damage-Free) loader is also coming into wide use. It is a freight handling device that is permanently installed in the car, and retracted to the roof when not in use. This loader permits a man to handle heavy and awkward loads by himself, without the usual crowbarring and general rough treatment of large shipments in closed cars. Pullman Standard makes another semi-loading shelf device, the "compartmentizer", which allows widely different sizes and types of shipments to be made in one car.

All of the above devices are used with boxed or crated merchandise, or in the case of automobiles, single objects. Box cars are also called upon to carry bulk loads such as grain of various types, and since the order of magnitude of the tolerances of box car door fits have never been very fine, leakage has always been a problem. Usually an inner wood door, called a grain door has been used to seal up the grain. This system, however, is bulky, clumsy, and not at all effective enough to warrant its trouble, although it is the one in general use. The Nystrom Company has recently brought out a standard box car door that is especially adapted to seal tight. This door uses the weight of the grain to seal the door edges against wedge-ground jambs, and only one small strip of disposable caulking cord is used on each door. The door requires no special installation other than its own runners, which fit a standard side exactly, and its fixtures are simple and well designed. It is coming into much use in the middle west now.

It is apparent that railroads are willing to pay for "extras" in design and function which protect manufactured freight in transit and facilitate loading and unloading. In 1950, manufactures and miscellaneous commodities constituted only 30.5 per cent of railway tonnage, but produced 45.9 per cent of freight revenue.



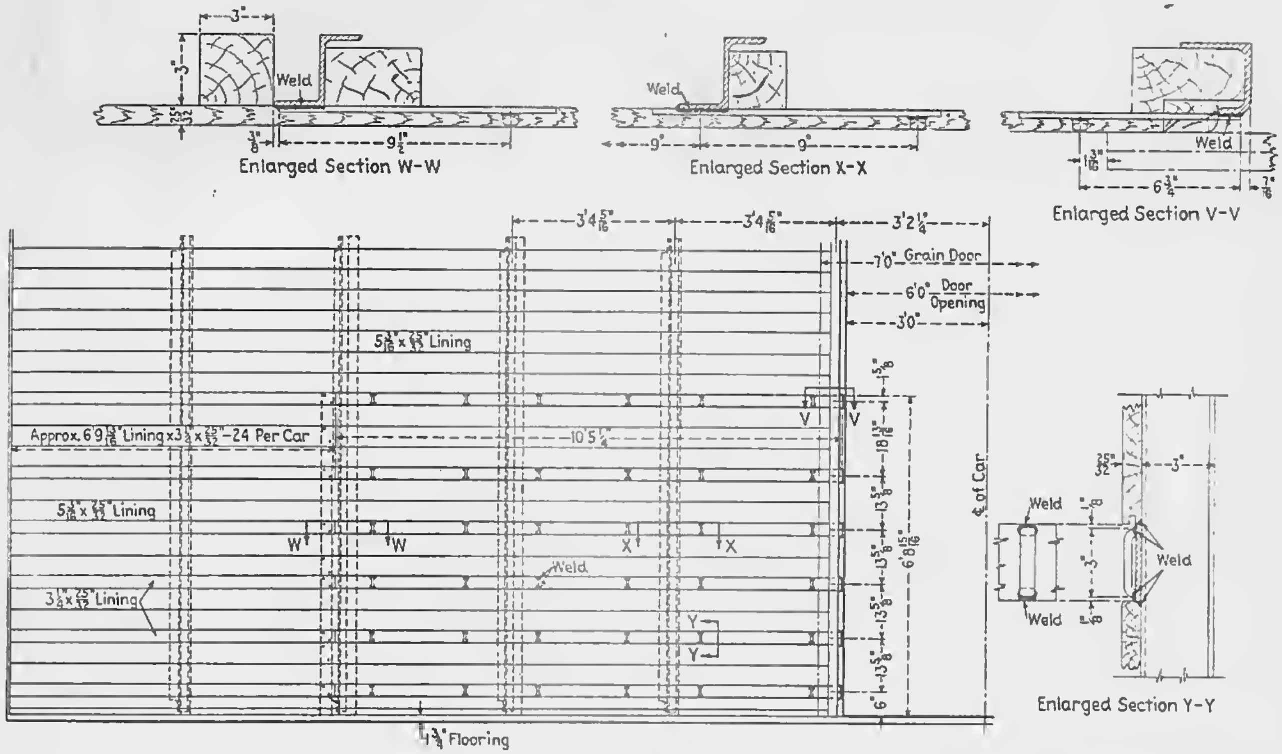
End elevation and sections of
Erie steel-sheathed box car.

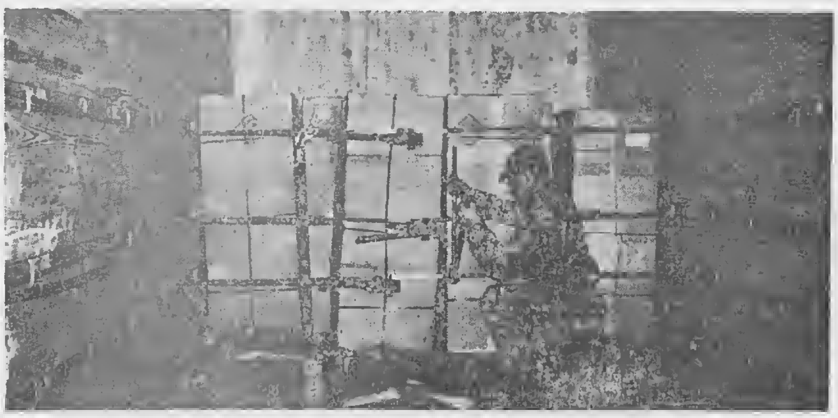
**Erie 50-ton, 40 ft. 6 in., steel-sheathed wood-lined box car. Series 82500-83199. Modified A. A. R. 1937 design.
Builder, American Car and Foundry Co.**

Inside, length 40 ft. 6 in., width 9 ft. 2 in., height 10 ft. 4 in., doors 6 ft. 0 in. Light weight 45,200 lb. (body 30,200 lb., trucks 14,400 lb.); load limit, 123,800 lb.: cubic capacity, 3,836 cu. ft.

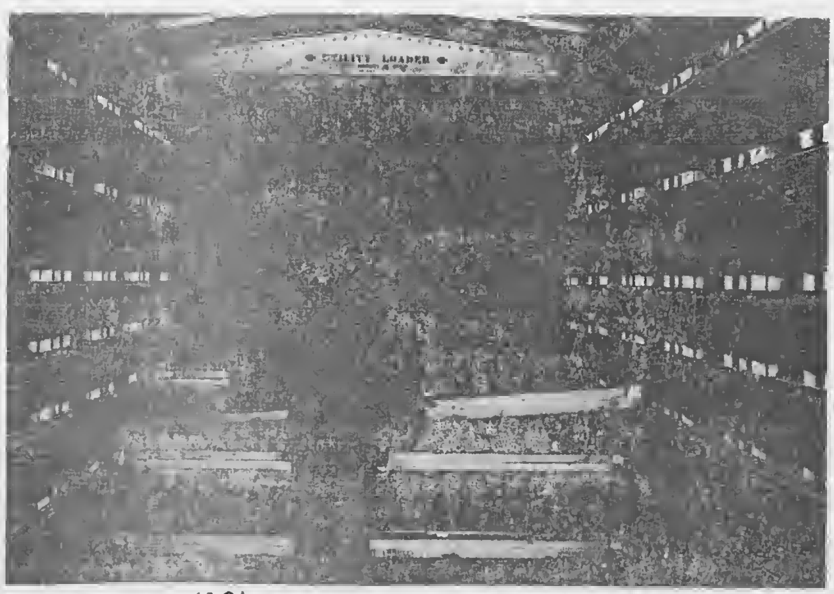
**Southern Roilwoy A.A.R. stondord 40-ton, 40 ft. 6 in., steel-sheathed wood-lined box car. Series 10000-15895.
Inside, 40 ft. 6 in., width 9 ft. 2 in., height 10 ft. 0 in., doors 6 ft. 0 in.**

Light weight 44,700 lb.; load limit 91,300 lb.; cubic capacity 3,712 cu. ft.

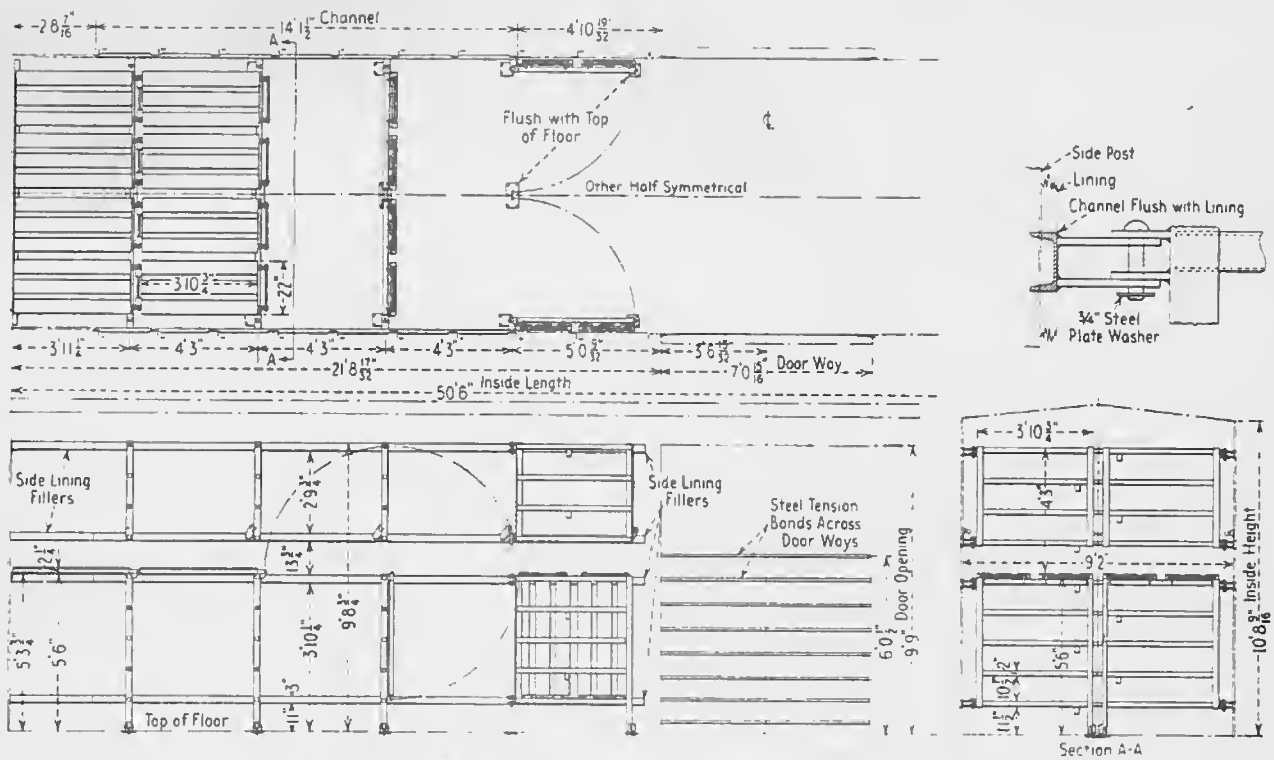




Above—Application of Economy (Barber) strap anchors to Erie box car. Right—Interior view showing method of retaining merchandise.



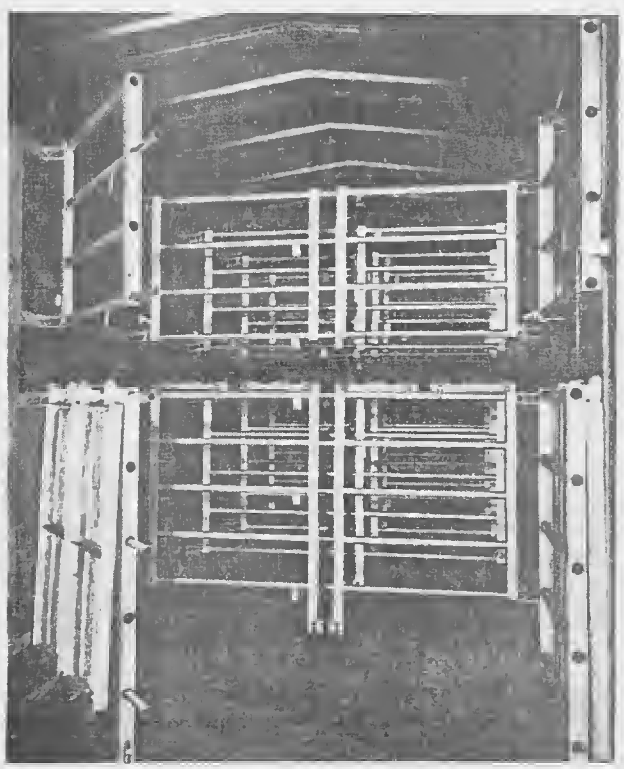
Bracing lading in car equipped with Evans "D/F Loader."

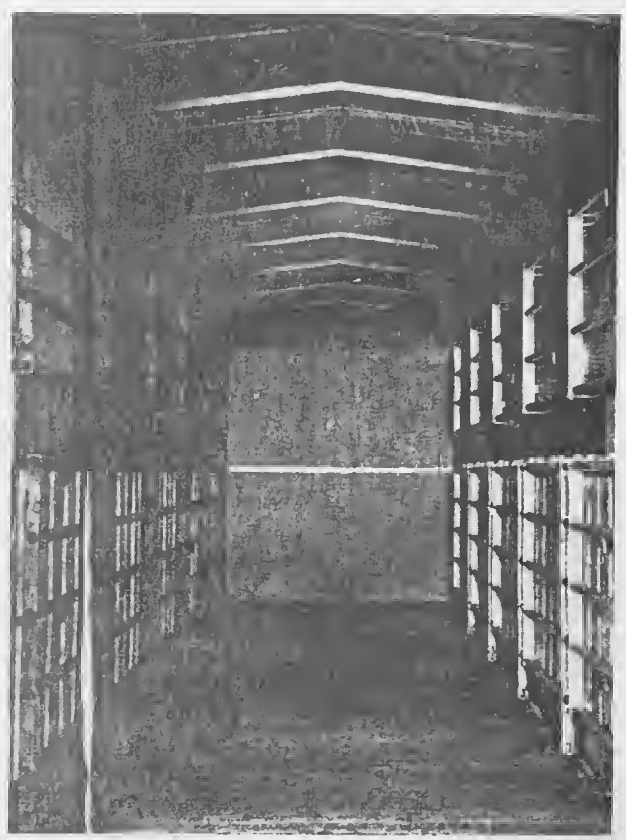


Collapsible, anchored type of Pennsylvania patented load retainer and separator.

Below left—All load retainers in position except those nearest door. Note shelves dropped to adjacent retainers for carrying second deck of lading.

Below right—Load retainers folded back before starting to load car.





INFORMATION SOURCES FOR FURTHER RESEARCH

"Modern Materials Handling", Boston

"Distribution Age", Simmons-Boardman, New York

"Modern Railroads", Chicago

"Flow", Cleveland

H. Cover, Asst. Vice President PRR, Philadelphia

C.K. Steins, Chief Engineer " "

P. Kiefer, Chief Engineer, NYCRR, New York

M. R. Brockman, Asst. Vice President, Southern RR, Washington, D.C.

B. Gunnell, Chief Mech. Engineer, " "

H. Urbach, Gen. Supt. Motive Power, Chi., Burl. & Quincy RR, Chicago

A. Kann, Gen. Supt. Equipment, Illinois Central RR, Chicago

F. Hosack, Gen. Supt. Car Dept. Chi., Rock Island and Pacific RR, Chicago

J. L. Morris, Gen. Mgr. Mech. Dept. Atchison, Topeka & Santa Fe RR, Chicago

J. Deppe, Supt. Car Dept., Chi., Mil., St. Paul and Pacific RR, Milwaukee.

Association of American Railroads, Mech. Div., Chicago

A.A.R. Library, Washington, D.C.

American Railway Car Institute, New York